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AN EVALUATION OF THE GROUNDWATER POTENTIAL AND ITS IMPLICATIONS ON CLIMATE: CASE STUDY OF ILORIN AND ITS ADJOINING AREAS, CENTRAL NIGERIA

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ABSTRACT
Borehole lithologic logs, Schlumberger Vertical Electrical Soundings (VES) as well as pumping test data been used to investigate the aquifer parameters of the underground system in Ilorin and adjoining areas. The aim is to ascertain the groundwater potential of the area. The static water levels were control correlated with the depth to basement contour. Five boreholes located at random within the area were pump tested. The aquifer system consists of two major aquifers and the overburden thickness ranges from about 4m to 35m. The yield of the boreholes were determined and found to be between 4325 ltrs/hr- 21600 litrs/hr, transmissivity using Jacob's analysis range between 18m^2/day, the permeability or hydraulic conductivity (k) found to be between 1.07 x 10^{-5} and 6.9 x 10^{-1}. These values are reasonably high and consistent with a large group discharge. Preliminary geochemical analysis shows that although $CaCO^{3-}$ and HCO^{3-} ions occur in higher concentrations compared with the Na^+, K^+, $C1^-$, Fe^+ and $S0_4^{--}$ but are still relatively lower than expected values from WHO standard. Generally, the water is of basement type with low storativity and transit time. The yield and depths to basement have been correlated, the correlation coefficient is 0.10. The correlation coefficient of the yield with static water level is 0.2. The two correlation coefficients are low which show a weak relationship. Climate change becomes of ever greater concern and although this issue is getting a great deal of attention, its effects on groundwater is still underexposed. By combining the yield and static water level correlation (0.0), with yield and depth to basement correlation (0.4) the study introduces an integrated perspective that has not previously been documented for this area. The results generate new understanding that can support groundwater resource development and management.

Keywords: Borehole, groundwater potential, basement, transmissivity, permeability, conductivity, climate change.

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INTRODUCTION

Groundwater may be defined as the water in the ground that will move or drain freely by gravity (Todd, 1980). It is the water beneath the surface where all the voids in the rock and soil are filled. Groundwater is the source of water for wells, boreholes and springs. Groundwater is very important as it represents 97% of all the available fresh water supplies on Earth but it is not every where available. It is therefore necessary and useful to know the tool and materials that can serve to utilize the system wisely. It is also important to examine in detail the origin, physics, chemistry, storage site, flow characteristics, the method of groundwater exploration and extraction, well drilling, development and maintenance techniques and the economic and legal consideration in groundwater use.

According to the International Groundwater Resources Assessment Centre (IGRAC), "Climate change becomes of ever greater concern and although this issue is getting a great deal of attention, its effects on groundwater is still underexposed". On the impact of climate change on groundwater they posited that "Increased variability in precipitation and more extreme weather events caused by climate change can lead to longer periods of draught and floods which directly affects availability and dependency on groundwater. In long periods of draughts there is a higher risk of depletion of aquifers, especially in case of small and shallow aquifers. People in water-scarce areas will increasingly depend on groundwater, because of its buffer capacity. According to them, 'Managed Aquifer Recharge (MAR), an adaptation measure, involves building infrastructure and or modifying the landscape to intentionally enhance groundwater recharge'. Ajayi, *et al.* (2022), in their research observed that the ground water success ratio is low in the basement complex and high in sedimentary terrains where aquifers are less patchy. The underground storage facilities or aquifers receive the supply of water by three method (Todd, 1980): (i) Direct percolation through fully permeable overlying strata (ii) Flow from a water course or lake (iii) Slow percolation through overlying strata of low permeability. At the beginning of the year in Ilorin, there is moisture deficit in the soil, and this continues for the first 18 weeks of the year (Oyegun, 1983). In May, there is marginal water surplus in Ilorin while in September is the month of maximum water surplus. Thereafter, there is return to moisture deficit in October. This type of cycle phenomena in the water budget makes irrigation agriculturally imperative for at least 6 months of the year, a period which unfortunately coincides with minimum surface water availability to lack of rainfall (Omorinbola, 1983). The water supply in Ilorin is predominantly from spring sources from Asa and Agba Dam. Recently, the importance of groundwater is being realized since some companies and individual are embarking on borehole drilling to supplement the water from these dams. Not much research had been done on the groundwater potential of Ilorin before 1980s despite the numerous boreholes sunk (Oyegun, 1983).

Writing on the water resources development and management in Ilorin metropolis and Kwara State, Oyegun (1983) described the geology of the catchment basin as consisting of mainly basement complex rocks; the older granite type and the undifferentiated types. The rocks in many places have been greatly weathered in situ and there are several pockets of weathered materials consisting of sand and sandy clay within the basin. Some of these pockets of weathered materials generally appear on the surface in many areas, for example, along the Asa river channel itself, and near the basic outline areas such as Ganmo. Oyegun (1983) used a typical borehole drilled at Philip Morris Company to describe the lithology. The well log showed weathering of the basement rocks.

However, the single borehole cannot give a meaningful appraisal of the ground water potential of all the areas under study. The UNICEF Assisted Water and Sanitation Project, the Middle-Belt/FGN EEC programme, the Kwara State Agricultural Development Program and the Kwara State Water Corporation have been drilling groundwater in Ilorin and its environs since early eighties. The work of the UNICEF project which started in 1984, forms the basis of analysis of this write up. The geophysical survey shows water is hosted in the overburden and fracture zones. In most cases within the Ilorin metropolis, the top soil is composed mainly of laterite followed by clay. The interpreted geophysical survey data have been accompanied with the lithological logging of the drilled holes. It has also been estimated that from the underground aquifer in basement rock complex in Ilorin using hand-dug wells and boreholes, the yield of water is about 16, 275 litres per hour (390600 litres per day) (Ayoade and Ayobande, 1978). With sudden yield capacity, such underground sources should be good alternative or complimentary water sources to surface water if the result is confirmed.

In 1986, both staff and students of University of Ilorin Geology department located a borehole point using terrrameter which was drilled by the National Water Resources Institute (NWRI), Kwara State in 1987. This has been followed later by many successful boreholes drilled by UNICEF project in Ilorin and its environs since 1999 to date. All these are sources of data for the present research. Olaoye (1990) carried out an undergraduate project on weathered basement aquifer in Ilorin and identified the aquifers at Ilorin as sands, weathered basement and fractured basement. The present research is one of the earliest comprehensive assessments of the ground water potential of Ilorin. It is aimed at assessing the situation of Ilorin, Kwara State capital, in central Nigeria based on the need to augment the surface water sources since the present water sources are grossly inadequate to meet the needs of the growing population. A pragmatic approach to solving this problem is harnessing groundwater sources. For proper planning on groundwater resources, a detailed assessment of aquifer characteristics is essential. The assessment is based on data from boreholes drilled by UNICEF assisted water projects in Ilorin and these include hydrogeologic logging/testing data. The chemical analysis had been done and limitations are in the area of standardization. A parallel has provided solution to the standardization problem (Olasehinde *et al.*, 1997). Pre-drilling feasibility studies carried out by the researcher for all the sites and the inferences from the sites have been correlated with the borehole log. The transmissivity, hydraulic conductivity or permeability (K) and average rate of yield (Q) have been determined for five boreholes. Although several studies have investigated groundwater conditions in Ilorin and its adjoining areas, there is still limited work that integrates the yield and static water level correlation (0.0) with yield and depths to basement correlation (0.4) for Ilorin and its adjoining areas. The absence of such integrated analysis presents a gap in understanding the broader geological controls on groundwater occurrence. To address this, the present study uses borehole logs, VES and other hydrological data to evaluate subsurface lithology and aquifer potential across the study area.

The research objectives included: (i) identification and documentation of the major lithological units present in five boreholes and VES locations within the study area (ii) correlation of these lithological units to evaluate their lateral continuity and spatial variability (iii) assessment of the groundwater potential associated with the identified subsurface materials (iv) provision of updated geological information that can guide future groundwater development and sustainable management.

Recent studies such as Olatunji, *et al*., 2025, Falade, *et al.,* 2025, Doro*, et al.,* 2025, Ameh, *et al*., 2025, Abraham and Emetere, 2025, Oyeyemi and Gomo, 2025 and Anukwu, *et al.,* 2024 highlight the need for enhanced subsurface characterization in the basement complex terrains of Nigeria due to inherent geological complexities that pose significant challenges to groundwater exploration, infrastructural development, and mineral prospecting. Inadequate characterization often leads to high rates of borehole and structural failures. These works emphasize how the geometry of aquifers in the Nigerian Basement Complex terrain is primarily shaped by secondary porosity-forming processes, namely intense weathering and structural fracturing since the original crystalline bedrock lacks primary porosity and permeability, so these post-formation processes are essential for creating the spaces that store and transmit groundwater.

MATERIALS AND METHODS (METHODOLOGY)

Location, Geomorphology and Physiography

The study area covers a part of Ilorin NW (Sheet 223) in the Nigerian topographical map. A Sheet comprises of ½ degree by ½ degree contour map on a scale of 1:100,000. The study area lies between latitude 8.43° N to 8.57° N and longitude 4.49° E to 4.65° E, occupying an area of about 271 km^2 in Ilorin the capital of Kwara State, Nigeria (Figure 1).

The areas considered are within Ilorin metropolis, Kwara polytechnic, Airport and Sobi barrack. The boreholes studied are located within these areas and are accessible by road.

The study area has an uneven topographic relief. The highest elevation above the sea level corresponds to the top of gneissic rock around Apata Yakuba and granite ridges around Budo Oyo village all within the metropolis, while the lowest elevation of less than 800 metre above the sea level occurs around the major stream. The area is well drained by various streams and their tributaries and distributaries which show dendritic drainage pattern. Asa river is the major river in Ilorin, while other rivers include Oyun and Aluko. Ilorin and its environs are situated in the tropical climate with two distinct seasons, the raining and the dry seasons. By virtue of its geographical location, she receives about 1500mm rainfall per annum, 90% of which falls between the months of April and October (Ilorin Airport Meteorological Station). The dry season extends from November to April each year. The temperature is on the average 27^0C the hottest period is within the dry season and the coldest period is around the wet season (Olasehinde *et al*., 1997). The mean monthly sunshine hours for Ilorin range between 2.5 and 9.5 hours with average of 5.9 hours (Ilorin Airport Meteorological Station).

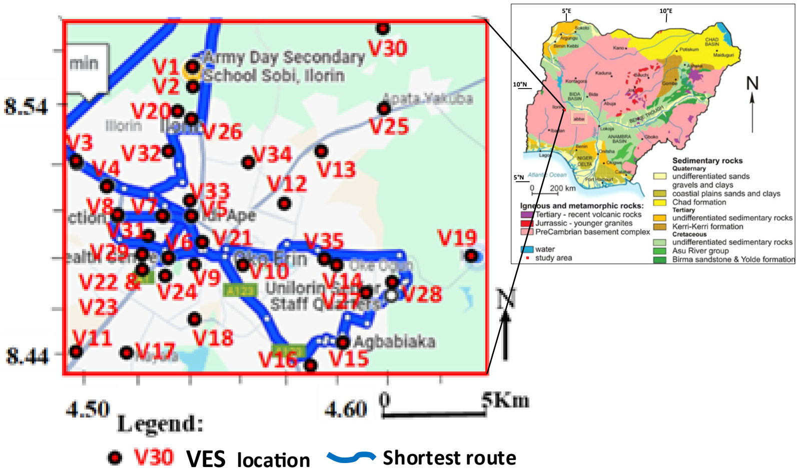


Figure 1: Sketch map of the study area (Inset: Geological map of Nigeria, Macdonald et al.,2005).

Geology and Hydrogeology

About 80% of the entire Nigeria is made up of crystalline rocks and about 80% of this belong to the basement complex (Oyawoye 1972). The basement complex extends in the west into the republic of Benin and in the East into Cameroon (Figure1). Rahaman (1988) grouped the basement complex of Nigeria into five groups according to chronological order and degree of metamorphism. These include: (a)Migmatite-gneiss complex (b) Slightly migmatized to unmigmatized paraschist and metaigneous rocks (c) Charnokitic rocks (d) Older granites (e) Unmetamorphosed dolerite dyke. The older granites form the bulk of the rocks in the study area. In solid forms igneous and metamorphic rocks are relatively impermeable and hence serve as poor aquifers. Where such rocks occur near the surface under weathered conditions, however, they have been developed by small wells for domestic water supply. Clay and Coarser materials mixed with clay are generally porous but their pores are so small that they may be regarded as relatively impermeable. Clayey soils can provide small domestic water supplies from shallow, large-diameter wells (Todd, 1980).

The geology of Ilorin and its environs can be described as crystalline rocks of basement complex of Nigeria, in which high grade metamorphic rock like gneisses and migmatite predominate at the subsurface while the top surface materials range from a mixture of clay, laterite and decomposed rocks in the upland areas to find saturated silty sand and clay in the river valleys. The present study area falls within the South-Western segment of the Precambrian basement complex of Nigeria. The major rock units within this segment are:

(i) the migmatite-gneiss complex which is presumably the oldest and the source rock of late Proterozoic younger sediments (Rahaman, 1988; Ajibade, 1990)

(ii) the schist belts which are commonly referred to as the younger meta-sediments consisting of low grade schists, phyllites slates and minor volcanics believed to have originated as rift-filling cover sequence on an older gneiss-schist basement

(iii) Pegmatite composing of microcline and quarts are occurring throughout the basement complex within the gneiss and older granites

(iv) Quartz-vein varying in thickness from a few millimeters to about a meter and which are concordant or discordant with the host rock

(v) Fluorite dykes occurring as tabular unmetamorphosed rock bodies cutting a cross foliation planes in the gneisses (Oyawoye, 1972).

Although, these rocks have low ground water potential as discussed earlier, places abound where there are thick weathered overburden and fractures which aid ground water accumulations (Annor and Olasehinde, 1996). The general geology of Ilorin, Kwara State, gives the impression that the city is not a promising ground water zone, the reason being that Ilorin lies on the basement rocks (Ayoade and Oyebande, 1978). The aquifers in the basement rocks are in patches. This is not to say that there is lack of groundwater. The earth crust holds water in myriads of columns and patches. The overburden, saprolite or neolith, can serve as ground reservoir for storage and transmission of percolating groundwater (Todd, 1980). The occurrence of ground water depends on the geology and rock characteristics such as porosity, specific yield and the coefficient of permeability and transmissibility, among other factors (Oyegun, 1983). Ground water flow describes the flow of fluid through the porous media in the earth's crust (Ayoade and Oyebande, 1978).

RESULTS AND DISCUSSION

Calculation of Ground Water Potential of Ilorin

The assessment of the groundwater potential of part of Ilorin has been based on the study of:

(i) Depth to basement

(ii) Static water level and

(iii) pumping tests data. From these and meteorological data from the Nigerian Airport, Ilorin, a fair assessment of groundwater potential has been made.

Depth to Basement Contour Maps

The study area falls within the basement complex of Nigeria. In the basement complex, groundwater prospecting depends mostly on the existence of structures in the subsurface and the thickness of weathering (Olorunfemi, 1990). The geo-electric sounding is therefore used to delineate the different structures, mainly fractures and the depth of overburden. Hydro-geologically, occurrence of groundwater is more favoured at the bottoms of the valley followed by the peak and the slope linking them (Olasehinde et al., 1997). The depth to basement contours and 3D surface maps were drawn based on information from geo-electric sounding (Figures 2 and 3) and borehole logs (Figures 4 and 5).

Geo-Electric Soundings Depths

All geophysical methods have limitations where the subsurface geology is complex and therefore, they are usually supplemented by the analysis of existing borehole records or the result of test drilling so the picture of the subsurface conditions become clearer and the feasibility of other borehole can be assessed more easily. Some locations were selected for electrical resistivity profiling using an ABEMS SAS 300 terrameter. Resistivity values picked through profiling werelater confirmed by vertical electrical sounding (V.E.S). The Schlumberger electrode configuration was used for the V.E.S using four galvanized iron electrodes.

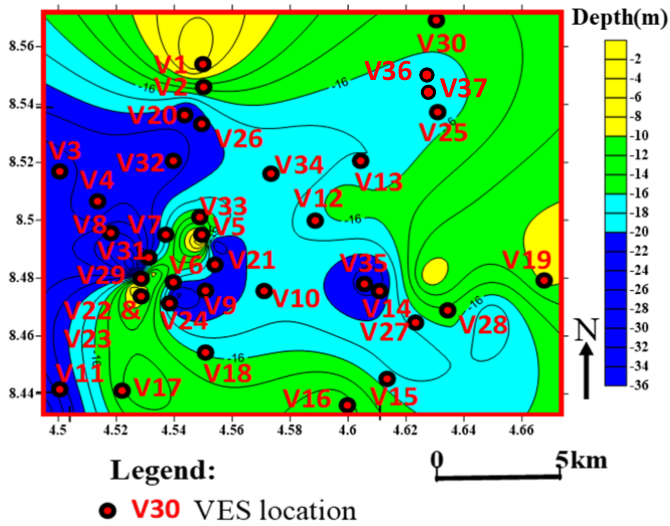


Figure 2: Contour map of depth to basement from VES

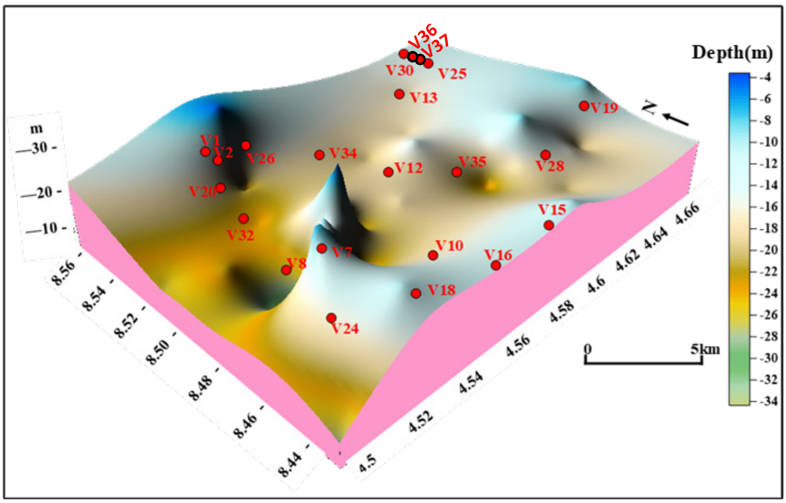


Figure 3: 3D map of depth to basement from VES 3D map

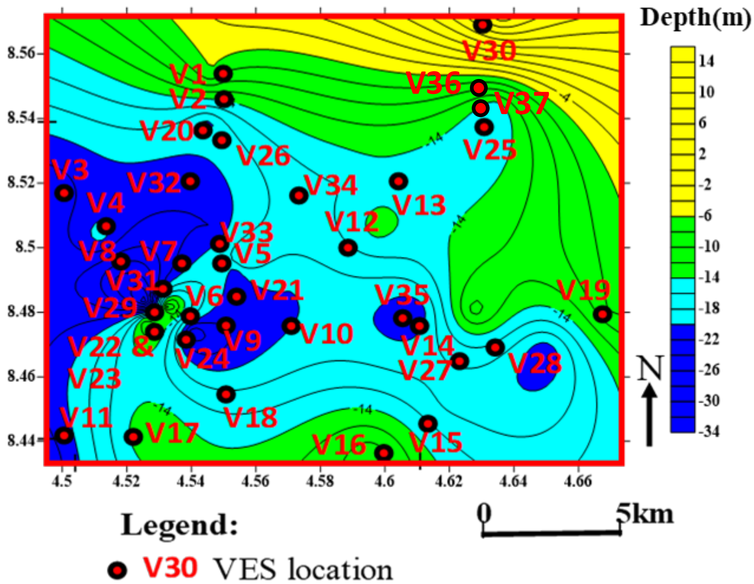


Figure 4: Contour map of depth to basement from drilling

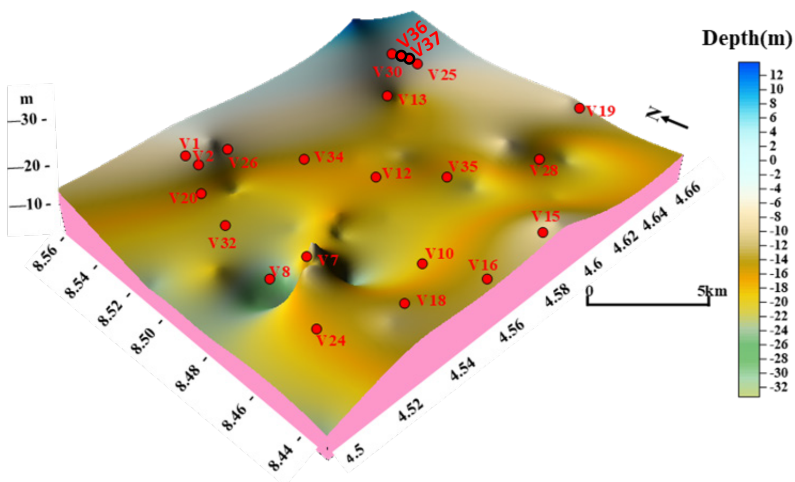


Figure 5: 3D Map of Depth to basement from drilling

The arrangement of the electrode is designed to measure approximately the potential gradient at the mid-point of the current electrodes (Telford *et al.,* 1976). The potential difference set up between the potential electrode resulting from the current that is fed into the ground allows the earth's resistance to be measured by the Terrameter. The resistance of the ground to the current is converted into an apparent resistivity (P_a) by applying the formula below:

P_a = KR where K is the geometric factor and R is the Resistance

$$R = \frac{V}{I}$$

where V = potential difference and I = current

$$Pa = \frac{\left(\frac{AB}{2} - \frac{MN}{2}\right)^2 X \; R \quad ohm\text{-}m}{MN}$$

Where K is the geometric factor, R is the Resistance, V = potential difference, I = current, AB = current electrode spacing, MN = potential electrode spacing and R = Resistance in ohms (Telford *et al.,* 1976).

For the vertical electrical sounding (V.E.S) the current electrode separation was increased step by step and the corresponding resistance measured until the maximum distance of about 100m (i.e. $AB/_2$) was attained. To obtain the apparent resistivity for each location, the resistance R is multiplied by the corresponding geometric factor. The apparent resistivities so obtained had been interpreted by curve inspection method and partial curve matching techniques using standard 2-layer curves prepared by Schlumberger (Todd, 1980; Telford *et al.*, 1976). The results of the depth to basement from VES studies are shown in Table 1. These depth in turn have been contoured as shown in Figures 2 and the 3D map as Figure 3. Thirty-seven (37) VES were picked for interpretation to prepare the basement depth map.

Table 1: Borehole Data for Contouring and Plotting of Graphs

No	Borehole location	Lon	Lat	SWL (m)	Depth to Basement (Drill) (m)	Depth to Basement(VES) (m)	Total Depth (BH) (m)	Yield Q (m^3/d)	App. Res(P) (Ω-m)
1.	Army DS Sch.	4.549158	8.552709	-5.0	-9.0	-6.5	-46.0	86.4	30.0
2.	Army Ba Sch	4.546433	8.553787	-2.5	-6.0	-4.0	-36.0	79.0	100.0
3.	F.G. Coll.	4.496839	8.516060	-6.0	-24.0	-26.0	-37.0	3011.0	76.0
4.	Oloje H. Est	4.511707	8.503350	-1.2	-19.0	-22.0	-25.0	138.4	73.0
5.	Idi Ape	4.552906	8.491805	-8.0	-22.0	-24.0	-33.0	140.0	78.0
6.	Oju Ekun	4.540546	8.474148	-3.5	-26.0	-25.0	-41.0	89.2	40.0
7.	Pakata	4.535053	8.491805	-2.0	-21.0	-20.0	-37.0	96.4	68.0
8	Ita-Amo	4.516514	8.491126	-4.5	-28.0	-30.0	-38.0	100.0	92.0
9.	Oja Ago	4.549870	8.492426	-6.0	-18.0	-2.2	-28.0	126.0	36.0
10	GRA	4.571126	8.486938	-2.3	-20.0	-18.0	-30.0	103.8	53.0
11	Airport	4.494486	8.432741	-3.0	-24.0	-28.0	-34.0	65.0	62.0
12	Niger B Area	4.597461	8.506094	-5.5	-13.0	-14.0	-50.0	36.9	45.0
13	Fate	4.608115	8.520315	-4.0	-15.0	-18.0	-29.0	241.9	78.0
14	TankeOkeOba	4.627654	8.480601	-7.5	-9.0	-8.0	-22.0	193.5	60.0
15	Agbabiaka	4.620679	8.453152	-4.0	-19.0	-20.0	-31.0	89.0	142.0
16	Olunlande	4.595713	8.436214	-8.0	-8.5	-10.0	-40.0	292.9	236.0
17	Odore	4.526994	8.442606	-3.5	-12.0	-10.0	-28.0	194.4	150.0
18	Unilorin Girls Hostel	4.670049	8.481334	-5.0	-7.5	-8.0	-25.0	124.0	138.0
19	Unilorin P.S.	4.673695	8.479035	-6.0	-8.0	-10.0	-43.0	220.0	76.0
20	I Kokoro N/Rd	4.544227	8.536416	-4.5	-19.0	-21.0	-25.0	115.0	133.0

21	Balogun Fulan	4.556187	8.495928	-4.0	-16.0	-18.0	-31.0	131.0	240.0
22	Midwifery S.	4.532379	8.481028	-4.0	-12.0	-10.0	-31.0	93.4	320.0
23	School Nurs.	4.532670	8.481476	-8.0	-6.0	-8.0	-18.0	132.2	62.0
24	UpGaAkanbi	4.541981	8.478629	-6.0	-19.0	-20.0	-31.0	76.3	220.0
25	Oyun (Poly)	4.634224	8.543248	-4.5	-16.0	-17.0	-28.0	102.0	160.0
26	Queens Sch	4.544419	8.537194	-5.0	-22.0	-24.0	-25.0	211.0	132.0
27	Unilorin Snr. Staff Qtr	4.636414	8.463073	-4.0	-19.0	-16.0	-45.0	518.4	165.0
28	Unilorin Staff Sch	4.649533	8.467678	-5.5	-22.0	-20.0	-44.0	136.9	55.0
29	Unilorin Mini	4.525746	8.477331	-6.5	-10.0	-6.0	-31.0	113.0	150.0
30	Ara Village	4.636043	8.572287	-5.5	-14.1	-15.0	-30.0	150.0	32.0
31	Adabata	4.525724	8.483087	-6.0	-34.0	-35.0	-46.0	215.0	150.0
32	Okelele	4.535910	8.520418	-3.0	-21.0	-24.0	-41.0	95.1	170.0
33	Kankatu	4.546437	8.506341	-3.5	-22.0	-18.0	-31.0	126.0	292.0
34	G.R.A II	4.586291	8.518962	-4.2	-16.0	-20.0	-40.0	120.0	250.0
35	Tanke Iledu	4.609635	8.480298	-2.5	-22.0	-24.0	-37.0	66.0	330.0
36	Poly (V2)	4.635250	8.556670			-13.9			
37	Poly (V4)	4.635510	8.556080			-15.9			

Depth to Basement from Borehole Logs

The selected sites from the geophysical method have been drilled by UNICEF drilling team. The depths to basement from borehole logs was collated (Table 1). The data collected was used to prepare the contour map (Figure 4). The thickness of the overburden ranges between (Drilling: -6 and -34, VES: -4 and -35m) (Table 1). The average depth of the basement rock is 17.01m. To the south-east, there is a deep weathering average of 20m depth. However, the probability of getting appreciable water yield in the area is greater where the overburden is thickest (Olorunfemi, 1990).

Static Water Level Contour Map

A water level indicator was used to determine the level of water in boreholes. The static water levels (SWL) of all the 36 selected boreholes were measured (Table 1). The static water levels range between -1.2 and -8. The static water levels were plotted on a map to prepare the static water level contour map (Figure 6). It has been found that the basement is deep where the static water level (SWL) is deep. There is a direct relationship between the basement depth and the static water level (SWL) as seen on the maps. Figure 7 shows the 3D surface map of the static water level (SWL).

Correlation of Depth to Basement and Static Water Level with Yield

The relationship between the depth to basement and the static water level (SWL) has been correlated. This is in turn correlated with the yield of the boreholes. A graph of yield against depth to basement from drilling has been plotted (Fig.8a). Similarly, the graph of yield against static water level has been plotted (Fig. 8b). These has led to the conclusion that the yield and the static water level (SWL) and the yield and depth have no linear relationship.

The erratic nature of the depth of weathering and inaccuracies of the driller's log could have also contributed to the scattered nature of the data.

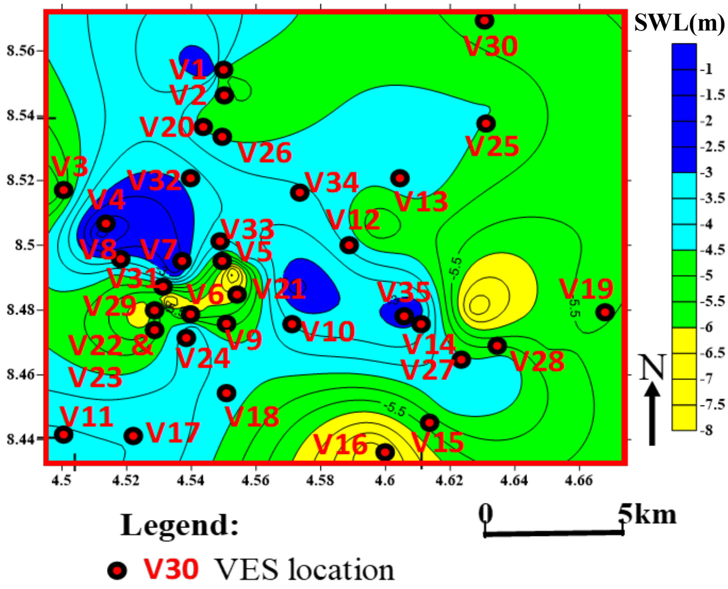


Figure 6: SWL contour map

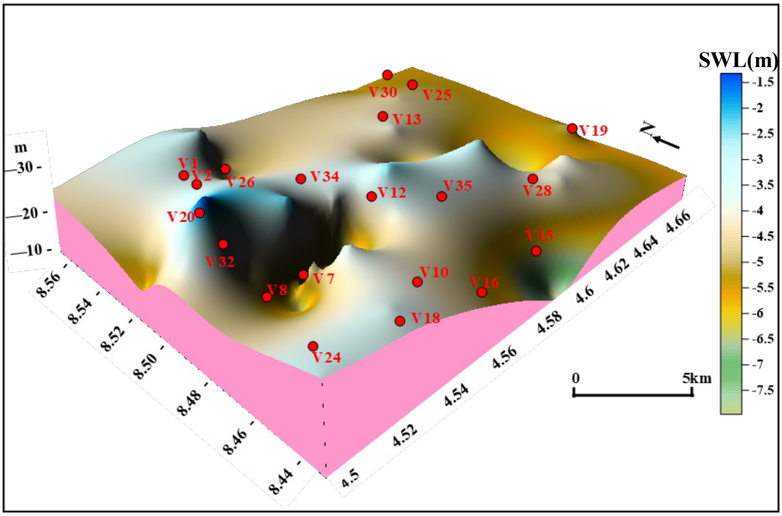


Figure 7: SWL 3D surface map

relationship between yield and depth (Fig. 8a) and also between yield and static water level (Fig. 8b). However, there is an existing relationship which will be found useful. The correlation coefficient (see below) of 0.2 between the yield and static water level is positive, but more significant than that between the yield and depth to basement from drilling.

This is not unexpected as discussed earlier- the inaccuracies of drilling logs.

Calculations of Correlation Coefficients

(i) **Yield versus static water level**

Let x_1= static water level, y = yield.

$$Rx_1y = \frac{nx_1y-(x_1)(y)}{\sqrt{[(nx_1)^2 - (x_1)^2(ny^2)-(y)^2]}}$$

$$= \frac{36(23546.28)-(171.15)(4734)}{\sqrt{(36\,x\,171.15)^2-(171.15)^2\ (36\ x\ 917169.98)\text{-}}}$$

$$Rx_1y = 0.038$$

Therefore, correlation coefficient between yield and SWL is approximately 0.0. This implies that there is no linear relationship between yield and SWL.

(ii)**Yield Versus Depth to Basement**

Similarly, the correlation of yield versus depth to basement has been done. The correlation coefficient (see below) of 0.4 is positive but not very significant. This shows that the greater the depth, the greater the unpredictability of borehole yield. There are boreholes with greater depth but with very poor yield and vice versa.

Let x_2 = static water level, y = yield;

$$Rx_2y = \frac{nx_2y-(x_2)(y)}{\sqrt{[(nx_2)^2 - (x_2)^2(ny^2)-(y)^2]}}$$

$$= \frac{36(32723.65)-(612.8)(4734)}{\sqrt{(36\,x\,612.8)^2-(612.8)^2\ (36\ x\ 917169.98)\text{-}(}}$$

$$Rx_2y = 0.48$$

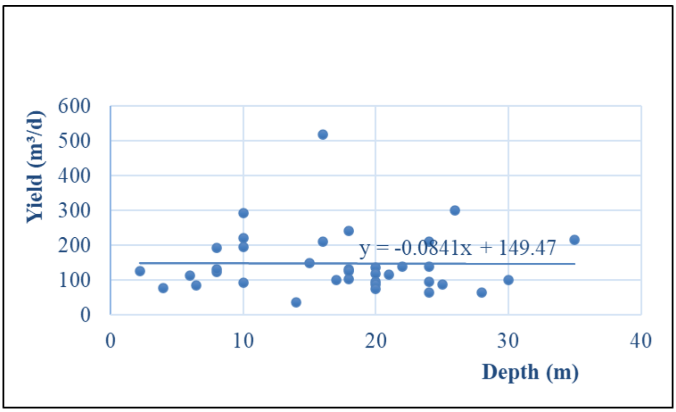


Figure 8a (i): Correlation between the Yield and Depth to Basement (VES).

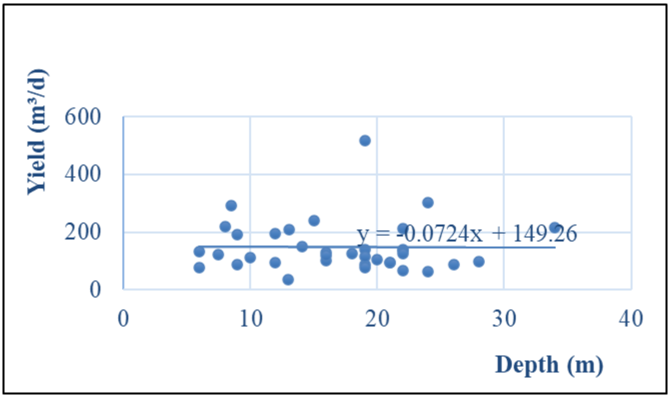


Figure 8a (ii): Correlation between the Yield and Depth to Basement (Drilling).

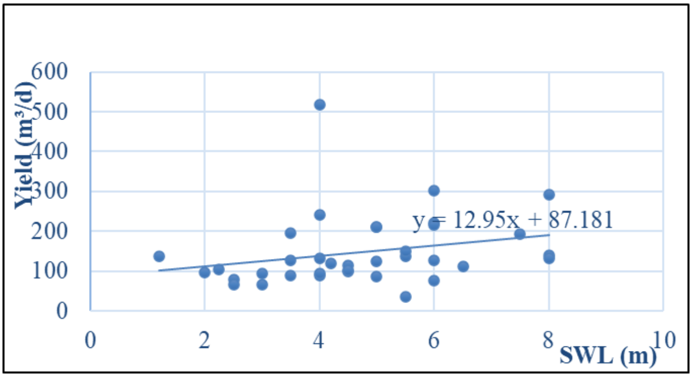


Figure 8b: Correlation between the Yield and Static Water Level (SWL).

Regression Equations

The simple linear regression graphs are plotted for both the yield versus static water level and depth to basement from drilling are plotted in Figures 8a and b.

Inspection of the scatter diagram (Figure 8b) reveals that up to static water level, the correlation of yield versus static water level was pump tested. The yield for most boreholes therefore was estimated to be sure that it could sustain hand pumping. The yields are shown in Table 1. However, special boreholes drilled were thoroughly pump tested. These are borehole numbers, BH_3, HB_{10}, BH_{12}, BH_{16}, and BH_{27}. The cooper Jacob straight line plot was done using the pumping test data in this study.

Formula

$$T = \frac{2.30}{4S}$$

was used to calculate transmissivity.

Where;

T = Transmissivity (m^2/day);

Q =Average discharge rate (m^3/day);

ΔS= Drawdown per log cycle

T =KDF (Where K = hydraulic conductivity or permeability)

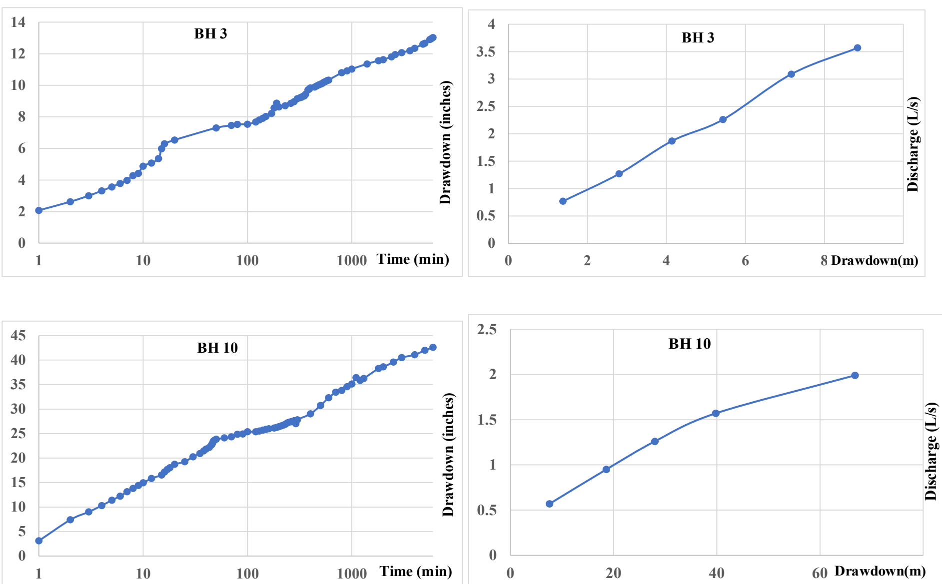
$$K = \frac{T}{BD}$$

(Where B = Thickness of saturated part of the water zone)

The value of Q was obtained practically while K and T are obtained using the above formulae for the five boreholes (Table 2). The Drawdown vs Time graphs were plotted. It was the constant rate pumping test that was done and the graphs are shown in Figure 9(a) while the drawdown against discharge graphs were plotted in Figure 9(b)

Table 2: The Values of Q, K And T for Five Special Boreholes Drilled

BH No.	Q(m^3/d)	T(m^2/d)	K(m/d)	D(m)
BH3	310.4	18	6.92×10^{-1}	26
BH10	103.8	3	1.07×10^{-1}	28
BH12	136.9	6	1.25×10^{-1}	48
BH16	292.9	11.0	2.86×10^{-1}	38.5
BH27	518.4	13.0	3.10×10^{-1}	42



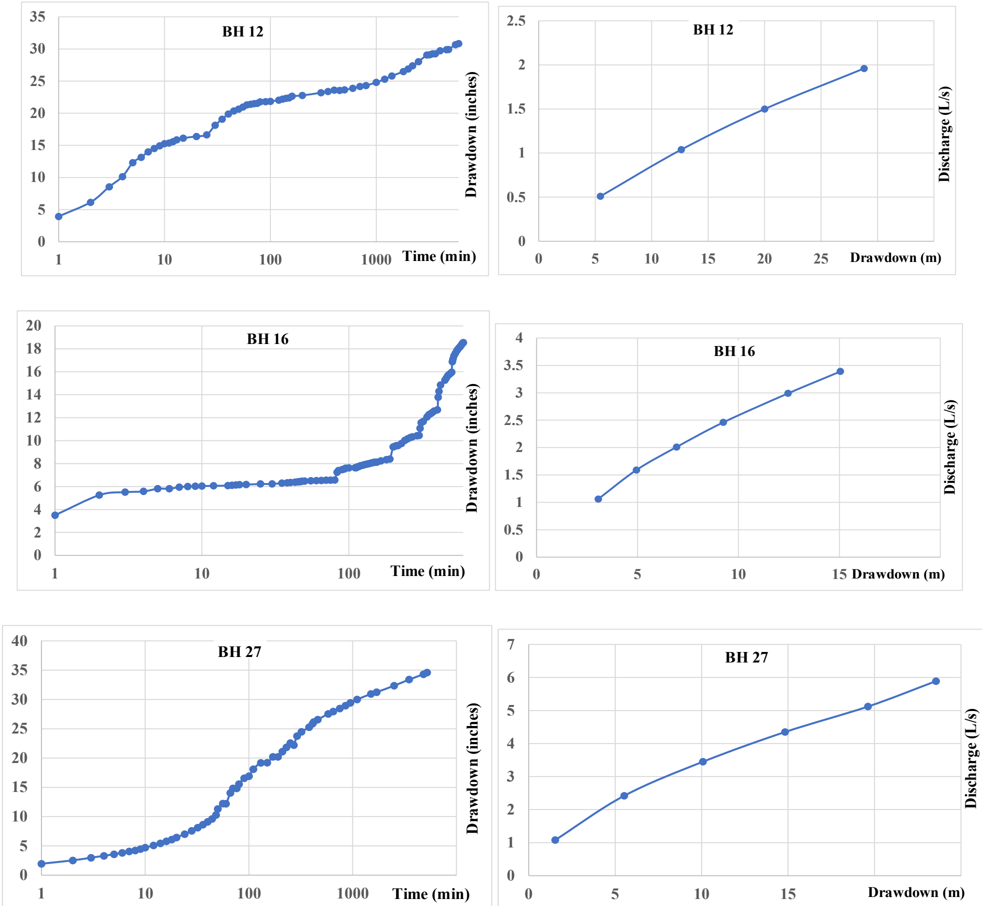


Figure 9(a): Drawdown vs Time for constant rate pumping test in Ilorin.
Figure 9(b): Discharge Vs Drawdownfrom pumping test in Ilorin.

DISCUSSION, SUMMARY AND CONCLUSIONS

Discussion

Using the available records of borehole logging, the geology of the subsurface was studied for five special locations within the study area, in addition the aquifer parameters of the aquifer horizons at different locations of the study area have been analyzed. Thickness of the overburden ranges between 4 and 35m. To the South-east, there is a thick weathering profile averaging 20m in thickness. Therefore, the probability of getting appreciable water in the area is greater where the overburden is thickest. Also, the resistivity reading is low at the area where the overburden is thickest and the values of depth to basement is high, where the basement is deep the static water level (SWL) is high. There is a trend of low depth to basement and low static water level along N-S of the location map. Along S-W, the basement is deeper and static water level is equally deeper. These suggest that the water is sourced from the overburden.

There is deep weathering where there is high topography, shallow weathering at the point where the topography is low. The yield is high at a high topography and deep weathering. This is so because the aquifers are of two types; the overburden and the fractured zone. So, the yield could be related to overburden and topography. The probability of getting water at the valley is high but difficult to hit the permanent aquifer.

The hydraulic conductivity values as seen in Table 2 are very high for basement aquifers. Thus, for a moderately good water bearing zone, cone of depression during the pumping test as indicated by the hydraulic conductivity value K is flat. A flat depression indicates a relatively small draw-down and high recharge rate for the five boreholes pump tested. Moreover, examining the value of transmissivity (T) as it relates to permeability (K) shows that transmissivity may be regarded as the permeability of a unit width of the full thickness of aquifer. The high values of T got for the five boreholes depict a good passage of water into the boreholes. Hence one can confidently say that the borehole is well developed to allow for laminar flow of water into it. Since the boreholes are located at different locations scattered around Ilorin and its environs, the radius of influence of the boreholes is assumed to be for the whole study area. The pumping of one borehole does not influence the other. This means that the boreholes are not tapping water from the same source and that the spacing of the boreholes is alright.

The statistical correlation shows that yield with static water level is 0. There is no linear relationship between yield and static water level. This implies that the yield of the boreholes does not necessarily depend on static water level (SWL). The correlation coefficient of the yield vs depth plots is 0.4. The difference is not very significant. The relationship is suggesting the same interpretation of the yield with static water level. When the yield versus static water level and the yield versus depth to basement are plotted on the graph, it shows no definite relationship. This study has enabled us to see how the groundwater could be used as supplement to the dam or surface water in Ilorin. The high values of K computed at the area (a basement terrain) for the five boreholes show that Ilorin and its environs have a good potential for ground water which could supplement the needs of the people.

Geophysical studies and logging of the boreholes show that the water is generally sourced from the fractured rocks in fresh basement and the overburden. Therefore, well design must be standard for ground water abstraction from the basement terrain. The water is of good quality chemically speaking and appears typical of basement water in central Kwara State, being high in calcium-bicarbonate and total dissolved solids and low in total suspended solid. Bacteriological examination of the water samples shows the number of coliform organisms to be very low and there is no evidence of fecal pollution of the water. The analysis undertaken are within WHO guidelines and the ground water should not pose any treatment problem.

SUMMARY AND CONCLUSIONS

Based on the geophysical studies it is seen that the geohydrologic setting of the study area comprises of two main hydrologic units; a weathered (Overburden) zone and fractured/jointed basement rock aquifer with variable yields as we have in locations BH3, BH10, and BH27. The thickness of the overburden varies from one location to another and the average thickness is 17m. Where the overburden is thick and highly fractured rocks, the yield is high.

The drilling at all the locations has typically penetrated a shallow weathered zone comprising of lateritic sand overlying sandy clay. Below the interface, semi-weathered and un-weathered basement rocks consisting predominantly of granite gneiss were encountered. The major aquifers were generally encountered below the interface in the basement rocks. The prediction of groundwater yield from static water level and thickness of weathering in part of Ilorin has been based on depth to basement computation from borehole logging, geoelectric sounding, meteorological data obtained from the Nigerian Airport observatory, pumping tests and aquifer characteristics. From the results of pumping test and using Jacob method of analysis transmissivity calculated was indicative of semi-confined groundwater. By combining yield and static water level correlation (0.0), with the yield and depths to basement correlation (0.4) the study introduces an integrated perspective that has not previously been documented for this area. The results generate new understanding that can support groundwater resource development and management. Considering the advantages of groundwater and the yield of the five boreholes pump tested, boreholes could be used to supplement water need of Ilorin and its environs. ‘Climate change becomes of ever greater concern and although this issue is getting a great deal of attention, its effects on groundwater is still underexposed’ IGRAC (2024).

RECOMMENDATIONS

As a result of frequent problems of dams such as lack of treatment chemicals, frequent breakdown of pump and problem of failure of electricity, it is advisable that ground water should be developed considering all the advantages of boreholes to supplement the dams.

To prevent boreholes from pollution, it is therefore suggested that a cement grouting should be done and if possible, seal off the surface water where the surface water is susceptible to pollution. Where there is high iron (Fe) contents, iron removal devices could be provided. This will enable us to reduce the iron content to the barest minimum. The installation materials used should be stainless pipes or PVC pipes. This will preclude any form of corrosion. Although the fractures in basement complex in most cases are not interconnected, however, boreholes should not be too close to each other so as to avoid tapping water from the same source. With the exception of the UNICEF Water and Sanitation Assisted project, from where basic data are got, most of these works and studies focused only on searching /discovery and exploitation of the groundwater information with respect to groundwater quality is generally lacking. A complete appraisal of available water resources in any area is commonly accomplished when aspects of water quality are included (Okagbue,1988). This study is therefore a complete appraisal of groundwater condition of Ilorin central Nigeria. The aquifer parameter of the study area has been fully analyzed. The groundwater has a good potential and the hydrochemistry of the water as well is suitable for both domestic and industrial use.

DECLARATION OF CONFLICT OF INTERESTS

The authors hereby declare that there is no conflict of interests.

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